AD 607996

REG. NO.
LOG. NO. 9-6525
WDSOT

(11) GM-TR-0165-00602

(7) SEMIANNUAL REPORT

ON

(6) INERTIAL COMPONENTS STUDY

1 July to 31 December 1958

Prepared for the Air Force Ballistic Missile Division
Headquarters, Air Research and Development Command
Under Contract AF 04(647)-165

(12)

(9) 31 Dec 58

(10) 34 p. incl. illus.
5 refs.

(13) NA

(14) Nil

(8) Prepared by L K Jensen
L. K. Jensen

Approved by G. A. Harter
G. A. Harter, Manager
Inertial Guidance Department

Approved by W T Russell
W. T Russell, Director
Electromechanical Systems
Laboratories

SPACE TECHNOLOGY LABORATORIES, INC.
P.O. Box 95001
Los Angeles 45, California

CONTENTS

		Page
1.	INTRODUCTION	1
2.	BACKGROUND AND STATEMENT OF WORK	2
3.	TASK AREAS AND ACCOMPLISHMENTS	3
4.	TECHNICAL PLANS	32
5.	BIBLIOGRAPHY	33

ILLUSTRATIONS

Figure		Page
1	HIG Gyro Test Set	7
2	Gyro Mounted on a Dividing Head	9
3	Gyro Mounted on an Environmental Holding Fixture	10
4	Block Diagram of HIG Gyro Test Set	11
5	Torque Balance Servo Constant Current Amplifier	12
6	Pictorial View of Servo-Driven Gyro Testing Turntable Type D	14
7	Block Diagram of Gyro Test Facility	15
8	HIG Gyroscope	17
9	Relay Servo System for Pulse Torque Tests of HIG-4 Gyroscope	23
10	Simplified Schematic of TDFF Gyro	28
11	Independent Gyro Torqueing Method	30
12	Closed-Loop Torquing Method	31

1. INTRODUCTION

Inertial guidance application to ballistic missiles is based upon the measurement of vehicle acceleration by instruments mounted within the vehicle. Since the inertial guidance system is entirely self-contained within the vehicle, there are none of the line-of-sight limitations or propagation disturbances found in radar guidance, nor is dependence placed upon clear weather for star sighting. One obvious merit of this system is the fact that no radiation to or from the vehicle is necessary. This guidance technique has the disadvantage, however, of accruing large errors in velocity and position over long flight durations. In view of this possibility, the necessity for precision inertial components to obviate such errors becomes clear.

Two of the integral components in an inertial guidance system are precision gyros and accelerometers. This report is concerned with various studies undertaken to evaluate inertial component hardware and test methodologies.

2. BACKGROUND AND STATEMENT OF WORK

In mid-1957 Air Force approval was given for the initiation of experimental studies in inertial component and measurement systems for support of systems engineering and technical direction of ballistic missile weapon system programs. These studies were also directed toward the rapid development and application of inertial components to future space and research programs.

The following primary tasks were undertaken in CY 1958:

a. An evaluation of Arma gyros and accelerometers.

b. A study of testing procedures for precision gyros.

c. A study of acceleration measurement techniques and testing methodology.

d. An evaluation of free floated gyro performance.

The technical approach to each task area consisted of three phases:

a. Study and survey.

b. Detailed planning and experimentation.

c. Analysis and report writing.

Proper recognition should be given to the fact that the experimental aspect of this program necessitated the use of certain government furnished precision inertial components not available commercially, as follows:

Item	Quantity Required
Arma gyro (4×10^7)	3
Arma accelerometer (Lot B)	3
Daystrom F20A-6 free gyro	3
Kearfott 424640-1-0 free gyro	3

3. TASKS AREAS AND ACCOMPLISHMENTS

3.1 An Evaluation of Arma Gyros and Accelerometers

The operational use of the Arma guidance system requires that internal adjustments be made to compensate for nonideal performance of the gyros and accelerometers. In accordance with this plan, it is important to know how long constants describing gyroscopic parameters will be reliable without recalibration of the system. It is additionally necessary to determine the effects of certain environmental flight conditions such as vibration and temperature on the accuracy of the accelerometers.

3.1.1 Study and Survey

Pursuant to the first task area, Space Technology Laboratories undertook a survey of the tests currently in use to measure drift torques of the Arma gyro with special emphasis on methods of determining the stability of various gyro drift rates. A knowledge of the effects of running times and environment on gyro drift is important inasmuch as this characteristic directly influences compensatory techniques as well as periodic checkout procedures employed prior to flight. As part of the survey, STL personnel visited Arma to observe gyro test equipment and procedures at first hand, and to discuss problems germane to these activities.

3.1.2 Planning and Experimentation

a. Arma Gyros

Following the survey, a plan comprised of three test phases was written describing the tests proposed to measure gyro drift rates and stability of drift rates over long periods of running time and under diversified control situations. The plan (GM 43.8-301) contains the objectives, background information, test descriptions, and requirements for test equipment.

Initiation of this study, however, remains contingent upon the arrival of the requisite government furnished hardware.

b. Arma Accelerometer

A test plan including special tests for the study of resonance problems in the Arma accelerometer was also written. The proposed tests were necessary adjuncts to the system engineering and technical direction of

the WS 107A-1 (Atlas) inertial guidance system. This plan (GM 43-461) contains detailed test conditions, minimal objectives, and program requirements.

Activation of this study was delayed until January 1959, when government furnished Arma Lot C accelerometers were to be delivered to STL.

3.1.3 Analysis and Report Writing

Priority considerations and consequent personnel deployment have necessitated a temporary delay in completion of the assigned task areas. Certain procurement problems, such as those involving Arma accelerometers and gyro units, have also contributed to this state of affairs. The work to be done for calendar year 1958 as per the performance schedule contained in Program Plan 165-18, however, has in large measure been accomplished. Analysis and reports in fulfillment of all contractual obligations will be issued as each task area is completed.

3.2 A Study of Testing Procedures for Precision Gyros

Present testing practices in the inertial component field have in the main been oriented toward either fire control systems or aircraft and ship navigation. While these procedures require guidance system precisions comparable to those employed in ballistic missiles, the latter are subject to considerably more stringent operating conditions and shorter operating times. An investigation of gyro and accelerometer testing methods is therefore necessary both to optimize the procedures for missile application and to provide standard acceptance criteria by which inertial products of various manufactures can be compared. The development of such criteria is a primary objective of this task area as well as of the program in general.

3.2.1 Study and Survey

A compilation of test procedures currently employed by the major producers and users of precision gyros is presently being made. A survey of this kind is necessary because of the wide variety of test practices in use today. This diversity makes the specification of a gyro's performance characteristic with respect to drift rate, for example, highly dependent upon the test procedure and equipment used to obtain this characteristic. It often happens in practice

that the means used to obtain a gyro characteristic bears little resemblance to the conditions under which the gyro is eventually employed.

In addition to these intrinsic reasons, the survey will materially aid in preparing preliminary test specifications for the third task area of the program plan. It should further serve as a reference for laboratory work and manufacturers participating in the survey.

Initial effort in the survey was devoted to research and study of the available literature on precision gyro products and testing techniques. Upon its completion the survey will answer such questions as the following:

a. What information is being sought by a given test?

b. How accurately does the test provide the information?

c. Why is the information desired?

d. How is the test performed and in what publication is it described?

e. How difficult, time consuming, and expensive is the test?

f. Is the test normally a laboratory or production procedure, or both?

g. On what type of gyro is the test normally performed?

h. Which tests are specifically used by the various firms surveyed?

Optimum tests for specific application will also be considered in the completed survey.

In addition to the accumulation of test procedure data, a tabulation of all important HIG gyros is being prepared showing physical and electrical characteristics, performance, and state of development. This tabulation will be important in the designing of test equipment as well as in test procedure planning. Since the tabulation is to include classified information, its distribution will be limited.

3.2.2 Planning and Experimentation

The importance of the survey and the amount of time consumed by it, and the fabrication of test set equipment (see Section b below) have prevented completion of this task area. In spite of these factors, however, work on this project has continued as indicated in the following sections.

a. HIG-4 Gyros

One HIG-4 gyro was received from the Reeves Instrument Corporation in November. This gyro, in conjunction with another HIG-4 on order, will be the subject of exhaustive testing during the checkout of the HIG gyro test set and the development of an acceptance test procedure for precision gyros. Pending the receipt of the second gyro, tests were conducted on the single HIG-4 which included (1) continuity and impedance measurements and (2) voltage output versus angle input scale factor. In addition to aiding in the determination of instrumentation requirements, these tests indicate that the gyro is within desired specification limits.

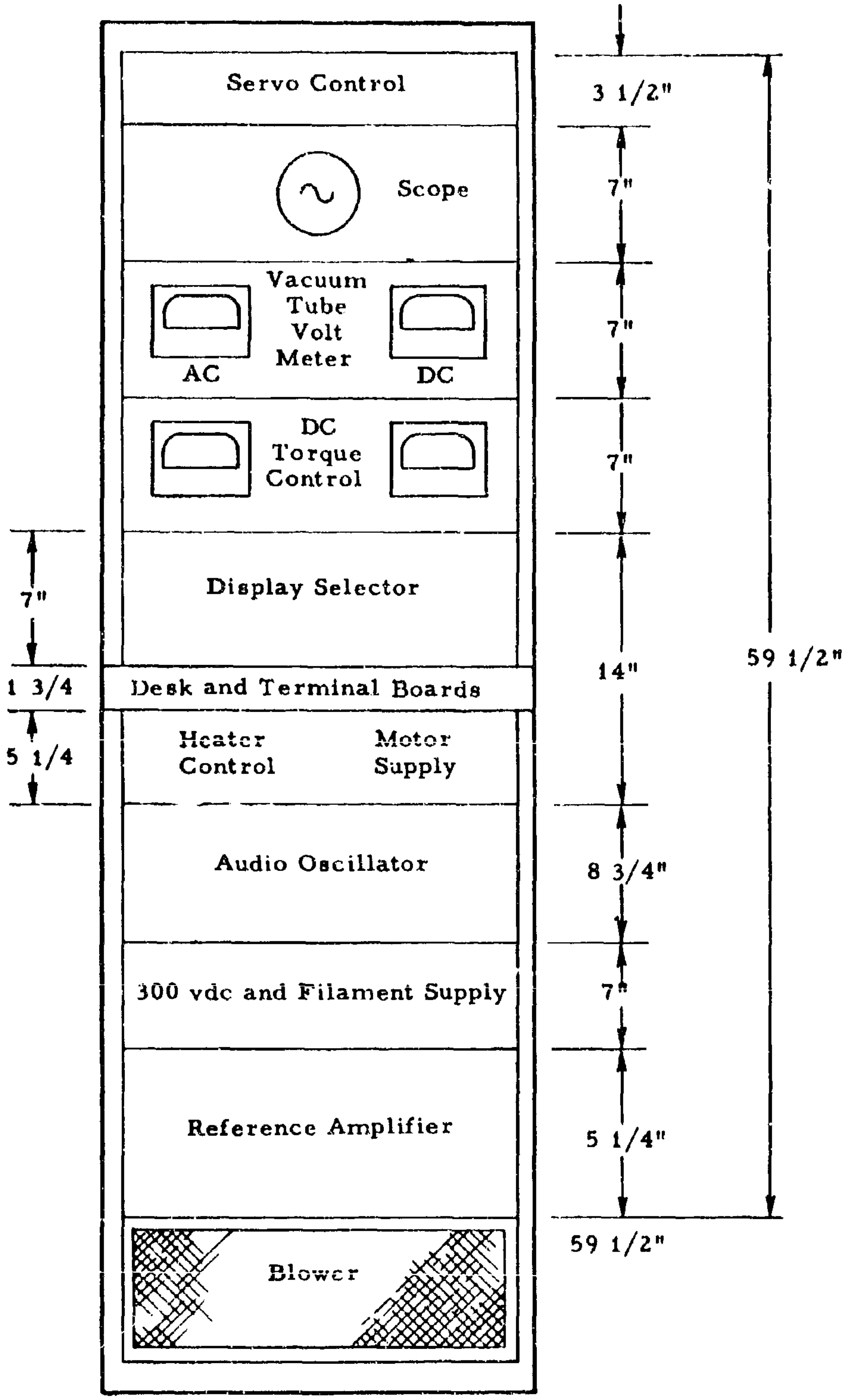
This acceptance type of test will continue and will be expanded to include investigation of such phenomena as the following: microsyn linearity and scale factor, reaction torques and restraints, friction and stiction, mass unbalance and shift, gyro time constant, axis alignment and null shift, compliance matrix and anisoelastic coefficient, dynamic unbalance, spin motor power variations, and transient and steady state thermal effects. Data accumulated on these tests will materially aid in determining meaningful test procedures, refinement of test equipment, and the understanding of HIG gyro phenomena.

The HIG-4 gyro will continue to be used in this program until quality inertial HIG gyros are available for laboratory use. A report on the capabilities of the HIG-4 as an inertial gyro will be prepared upon completion of laboratory tests.

b. HIG Gyro Test Set

A major effort in the second task area was expended on the development of a HIG gyro test set with a wide range of flexibility. Some of the outstanding features of the test set are the variety of tests and gyros to which it is applicable, a precision adequate to all contemplated tests, ease of alignment and amenability to panel control, and a compactness allowing portability for use at environmental test locations.

The test set is packaged in a single bay as shown in Figure 1. It contains built-in meters for alignment and test monitoring with jacks for external meters where greater accuracy is required. Connections to the gyro can be made


Servo Control
3 1/2"
Scope
7"
Vacuum Tube Volt Meter
AC
DC
7"
DC Torque Control
7"
7"
Display Selector
1 3/4
Desk and Terminal Boards
14"
59 1/2"
5 1/4
Heater Control
Motor Supply
Audio Oscillator
8 3/4"
300 vdc and Filament Supply
7"
Reference Amplifier
5 1/4"
59 1/2"
Blower

at the testing desk. The gyro may be mounted on a dividing head as shown in Figure 2 or on an environmental holding fixture as seen in Figure 3. These systems are further discussed in Section c following.

A block diagram of the test set in a common servo mode of operation is shown in Figure 4. The signal travels from the gyro signal generator through the input compensation networks to the preamplifier, which has a maximum gain of over 100 volts/volt, through the demodulator with a gain of one to the dc amplifier, which has a maximum gain of approximately 20 ma/volt, and finally back to the torque generator.

The input compensation network consists of variable resistive and capacitive loading for restraint compensation, quadrature compensation, filtering for harmonic rejection, high impedance phase correction, and a null shift allowing servo operation at any gimbal position.

The demodulator is a full wave phase discriminator bridge type requiring no shaping network because of the high frequency response of the system compared to that of the gyro. The Inertial Components Laboratory has designed a new dc amplifier utilizing transistors with a common base output and arrayed in complementary system as a safety precaution to avoid high voltages on the torquer windings. A schematic diagram of the circuit is shown in Figure 5. The servo has low drift, is stable and easily aligned, and is suitable to high and low torque operation. A feature of the dc torquer excitation is the utilization of a special demagnetization circuit to eliminate hysteresis effects.

In conjunction with suitable recorders and precision meters, the HIG gyro test set can perform almost every test required of a HIG gyro except servo drift tests. Tumbling tests can be performed with a rate turntable or more simply by turning the gyro to fixed intervals or steps in its holding fixture. Two or more gyros can also be tested concurrently depending on the test. Power requirements are 117 volts, 60 cps, single phase; 117 volts, 400 cps, three phase; and 28 volts dc.

Figure 3. Gyro Mounted on an Environmental Holding Fixture.

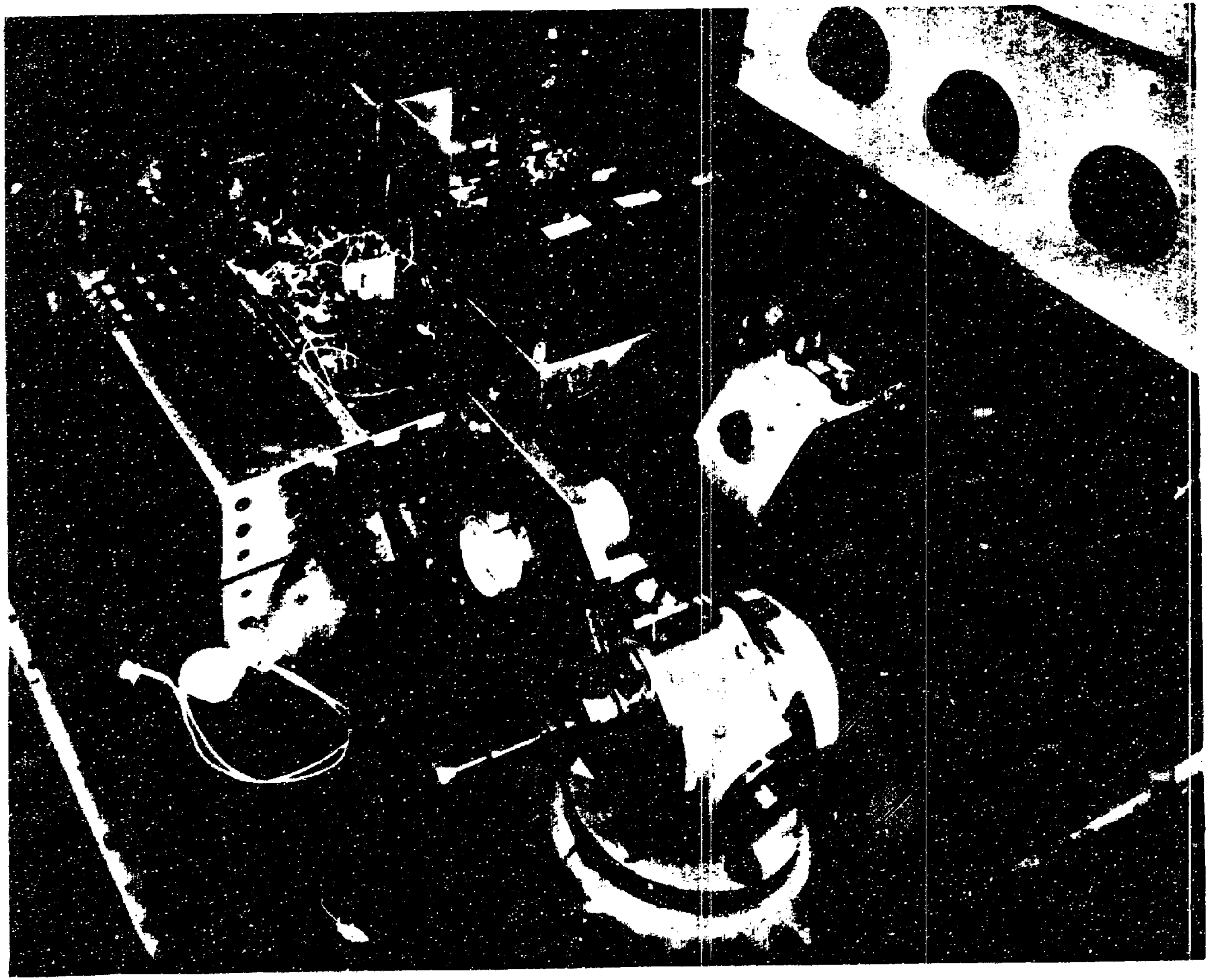


Figure 2. Gyro Mounted on a Dividing Head.

Figure 3. Gyro Mounted on an Environmental Holding Fixture.

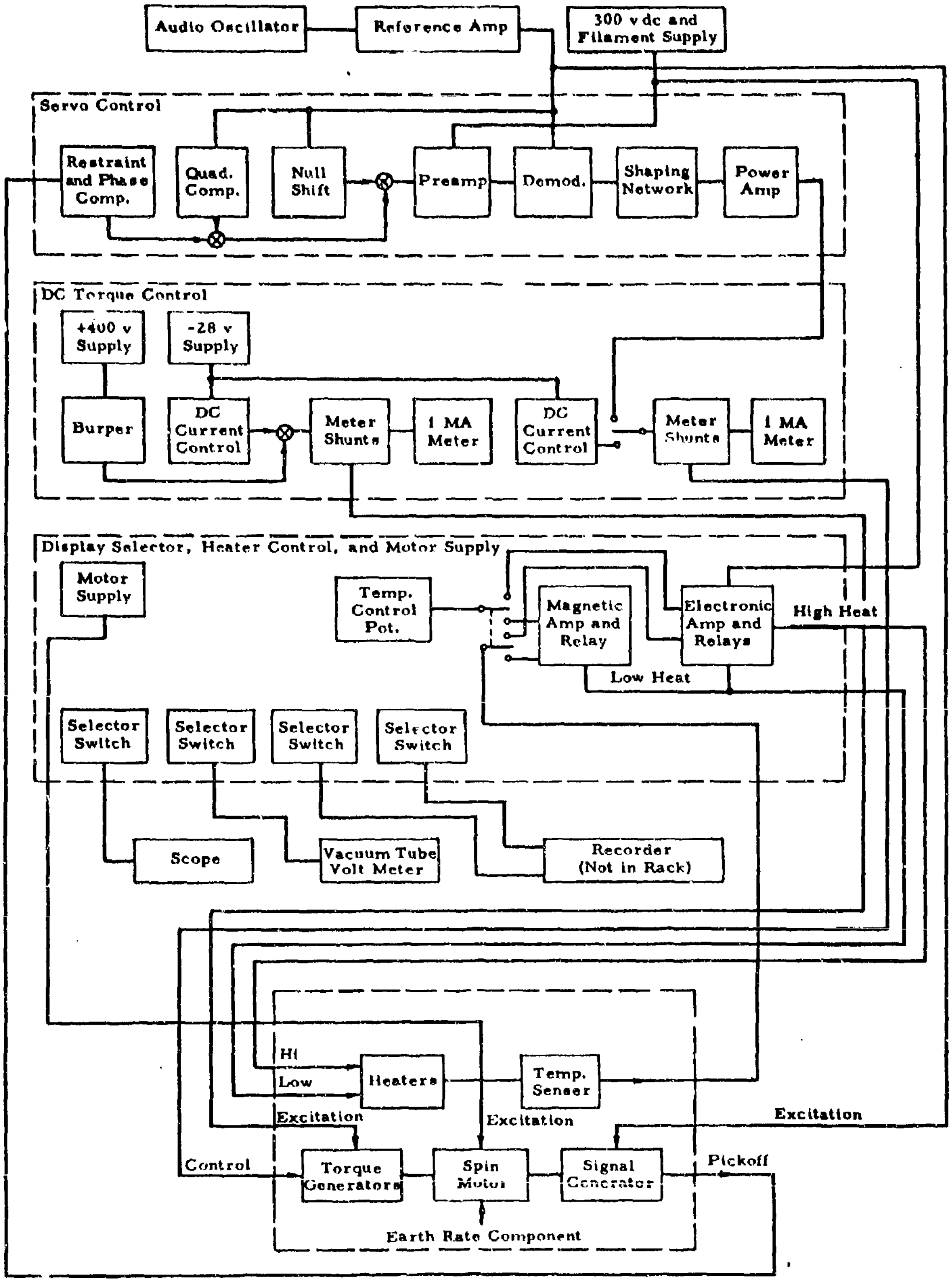


Figure 4. Block Diagram of HIG Gyro Teat Set.

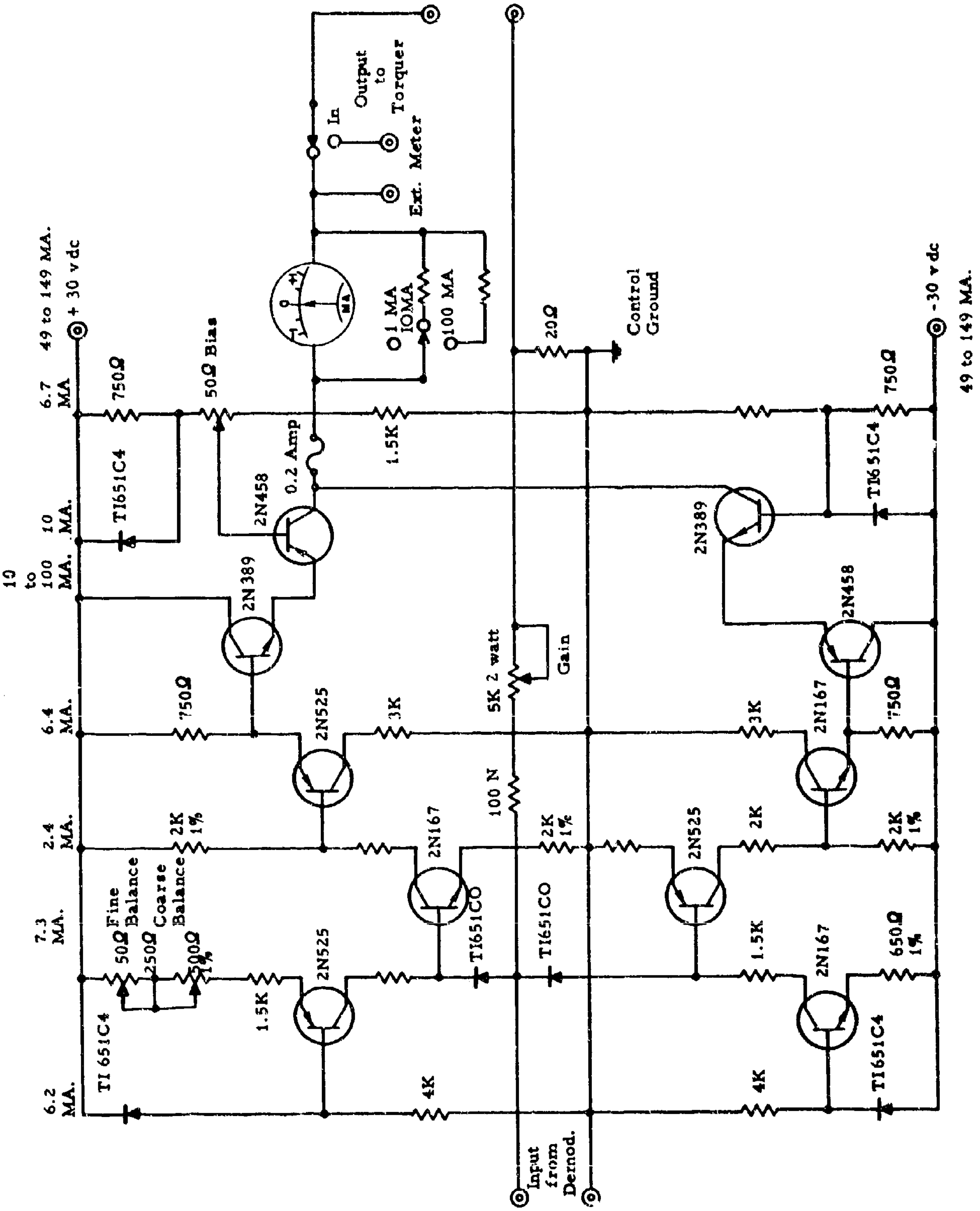


Figure 5. Torque Balance Servo Constant Current Amplifier.

c. Inertial Gyro Test Facility

In order to evaluate the performance of an inertial gyro, it is necessary to have a knowledge of the environment in which the gyro is operating and to be able to vary precisely the environmental factors to which the gyro is most sensitive. Since most inertial gyros are hermetically sealed and temperature controlled, the two environmental factors to which the gyro is most sensitive are rotational velocity and acceleration. Since both of these factors are evident at any earth fixed test site, it is necessary to know the direction and magnitude of the earth's sidereal rate of rotation and the direction and magnitude of the earth's gravitational field at the test site.

Once environmental influences on the gyro have been quantified, the intrinsic performance of the gyro is evaluated by measuring the increment of change between known gyro input and observed output. This could be accomplished by placing the gyro case in various orientations, which are precisely known, and measuring the gyro signal generator response in each of these orientations. This open-loop technique lacks desired precision because the gyro rotor orientation varies with respect to the gyro case during the test thus modifying the precisely known inputs. In addition, the gyro signal generator lacks the required angular reading accuracy to evaluate gyro performance.

To circumvent these shortcomings in the open-loop test, the gyro may be operated as a null-seeking device in a closed-loop servo system. The gyro performance is then deduced from the closed-loop servo system response. A properly designed servo will maintain the float orientation fixed with respect to the gyro case and will thus essentially eliminate the signal generator resolving accuracy as a factor in the measurement of gyro performance.

To satisfy the conditions of orientation and closed-loop servo testing, the Inertial Components Laboratory of STL has ordered and received a precision gyro servo table manufactured by J. W. Fecker, Inc., according to the MIT Model D design. The servo table is illustrated in Figure 6. A block diagram of the associated electronics equipment is given in Figure 7. As seen from Figure 6, the gyro is mounted on the turntable surface which is free to rotate about the turntable axis. This axis is driven by a direct drive servo motor and

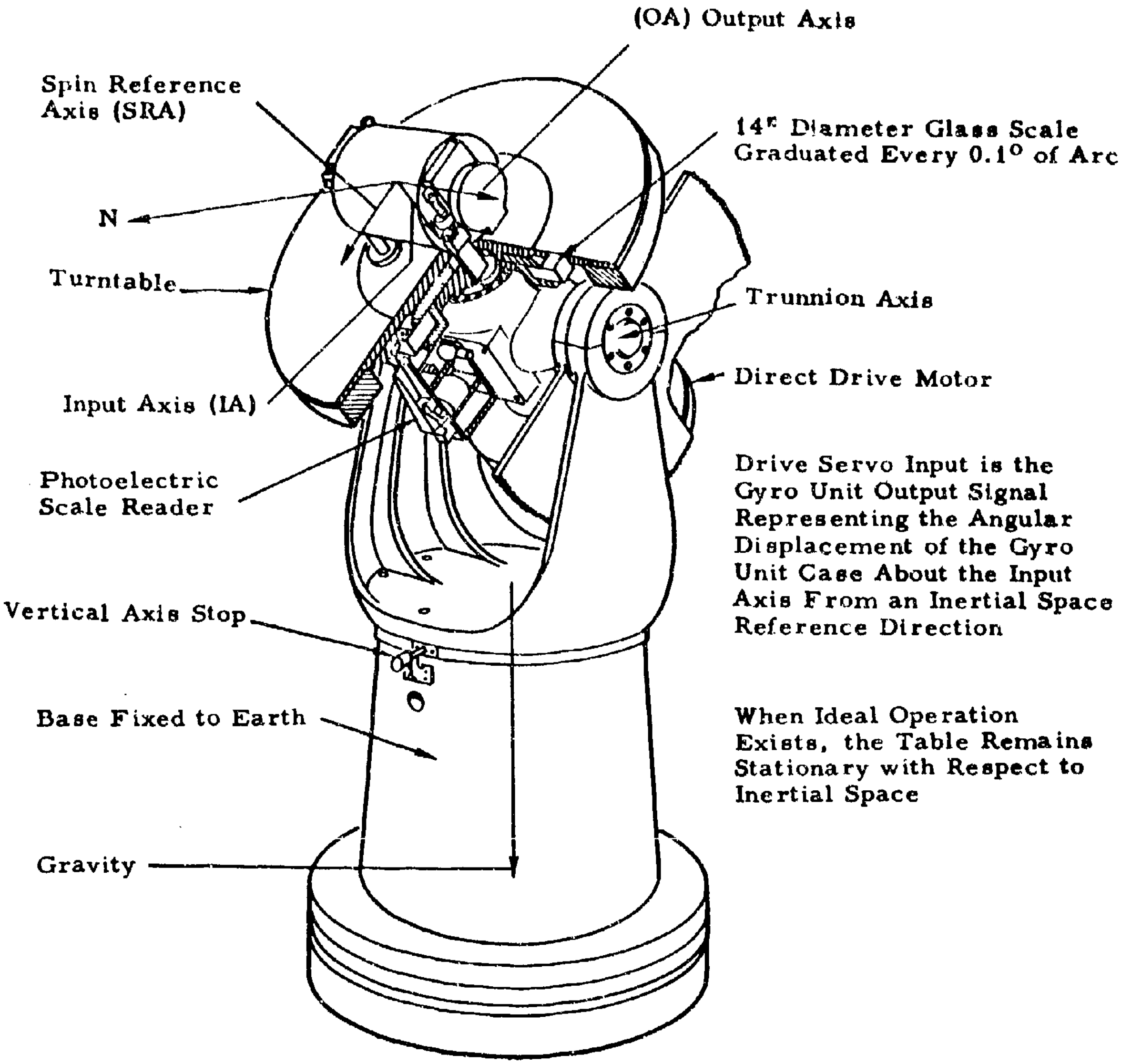


Figure 6. Pictorial View of Servo-Driven Gyro Testing Turntable Type "D."

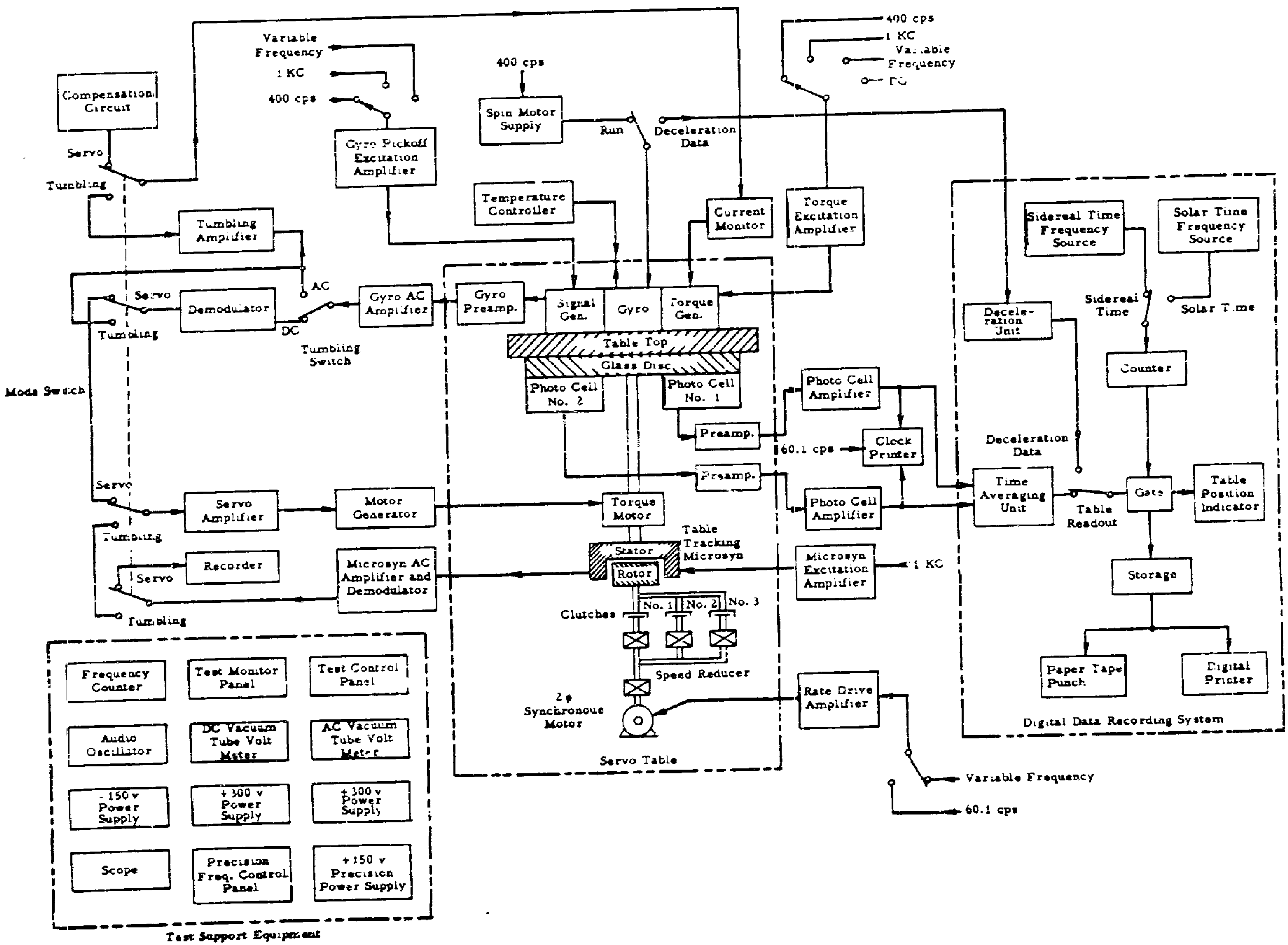


Figure 7. Block Diagram of Gyro Test Facility.

has unlimited freedom of rotation. By means of a trunnion, the turntable axis may be positioned at any angle ±100 degrees from the vertical. Positioning of the trunnion axis about a vertical axis is also possible, thereby fulfilling the orientation requirements specified in the preceding paragraph.

Although the servo table may be used to test two-degree-of-freedom gyros as well as single-degree-of-freedom gyros, the balance of this discussion considers only the testing of single-degree-of-freedom gyros in a closed-loop servo system. A single-degree-of-freedom gyro is shown in Figure 8 and has been described in detail elsewhere.* Due to a high damping coefficient in the gyro, the float moves with an angular velocity proportional to the sum of the torques applied to the float about the ouput axis. These torques can be classified as follows:

(1) Signal Torques

(a) Precessional torque due to rotation of the gyro case about the input axis.

(b) Torque created by a current passing through the torque generator.

(2) Error Torques

(a) Fixed torques due to the action of the signal generator, torque generator, and flex leads on the float.

(b) Acceleration sensitive torques due to acceleration acting on the noncoincident center of buoyancy and center of mass of the float and anisoelastic properties of the float.

(c) Cross coupling torques due to misalignments within the gyro unit.

(d) Random torques due to motion of the damping fluid, variation of the pivot friction, shifting of the center of mass of the float, shifting of the center of buoyancy of the float, etc.

---

*Single-Degree-of-Freedom Gyro Units for Use in Geometrical Stabilization Systems, MIT Report 6398-S-11, 1950.

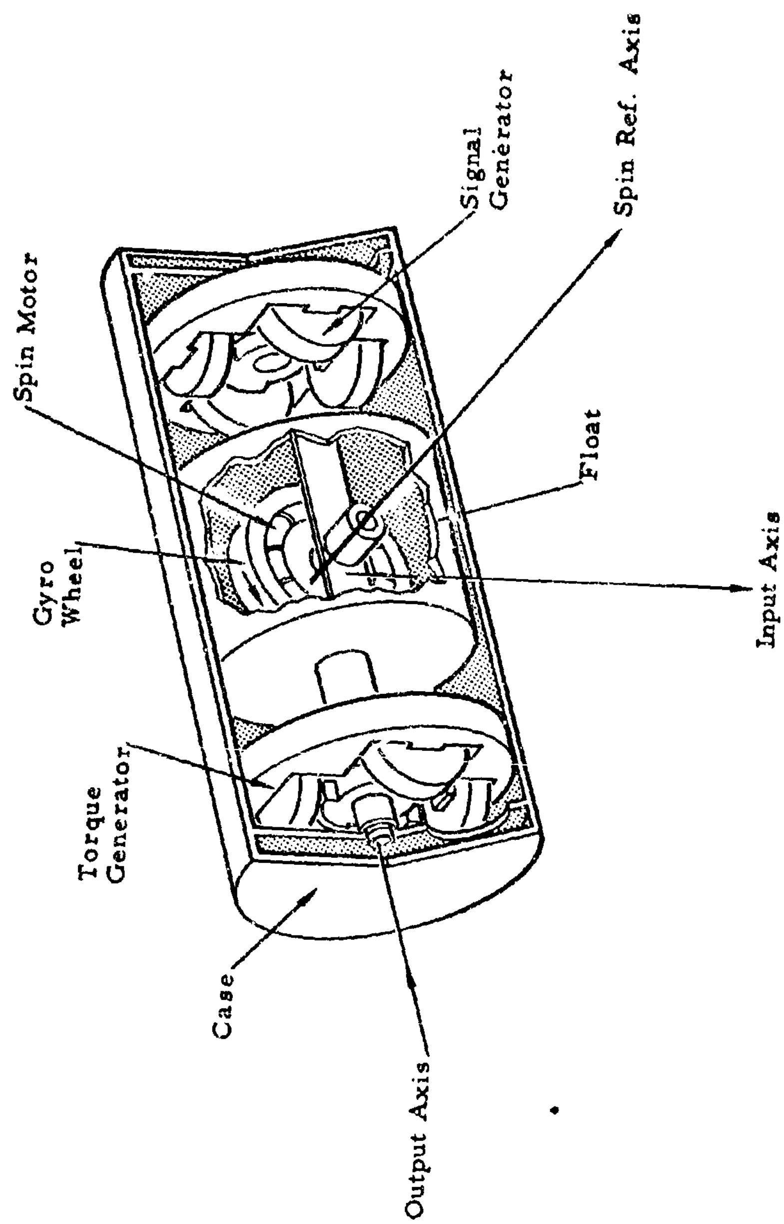


Figure 8. HIG Gyroscope.

To maintain the gyro float at the desired orientation with respect to the earth's gravitational field and the earth's polar axis, (as defined by the servo table), it is necessary to introduce or modify one of the signal torques so that the sum of the torques acting on the gimbal is always equal to zero, thereby preventing any appreciable motion of the float. This may be accomplished with a closed-loop servo system by sensing float motion with the gyro signal generator and correcting the appropriate signal torques by means of a servo amplifier. Two types of servo systems are possible depending on which signal torque is used to rebalance the float. In the first case (precessional torque), the output of the servo amplifier is used to operate the direct drive servo motor of the servo table, thus rotating the table and gyro case. If the second signal torque is used (torque generator torque), the servo amplifier is connected directly to the torque generator. The torque created on the float is then proportional to the current in the control winding of the torque generator.

The first type of test is called a "servo test", and the output data are obtained by observing the position of the table at known increments of time, thus determining the angular velocity of the gyro. The table position can be measured to an accuracy of about 3 seconds of arc and the time can be easily determined to fractions of a millisecond. Angular rate measurements can thus be made very precisely. The second type of test is called a "current balance test". The precision of the output data in this case is limited by the accuracy of the torque generator, which may be in the order of a few per cent. Since the closing of the servo loop forces the total torque acting on the float to zero, the measured signal torque is equal and opposite to the sum of the error torques listed above. If the functional form of the various error torques is assumed to be known, the data can be decomposed into contributions from each error source.

The STL gyro test facility is similar to facilities presently in operation at MIT, AC Spark Plug, Detroit Controls, Reeves Instrument Company, Litton Industries, and other industrial organizations. The requirement for an inertial gyro test facility at STL, however, is based on the Inertial Components Laboratory program of evaluating existing inertial gyros and establishing inertial gyro testing techniques. These considerations dictate a different philosophy of test facility use, operation, and design than encountered at other facilities

where gyro development and gyro production tests are conducted. The STL philosophy of operation requires a more versatile and flexible test facility which can be rapidly changed to conduct different types of tests or to test different types of gyros.

To accomplish these objectives, the following changes and improvements are being incorporated in the STL test facility.

The servo table has been modified to:

(1) Include a precision rate drive capable of rotating the table at precise velocities of 15 deg/hr to 1 deg/sec. The rate accuracy is limited by the ability to set and maintain the frequency supplied to a synchronous motor. The turntable servo amplifier and torque motor are used as a follow-up servo, using a table tracking microsyn to sense the difference between table position and the output shaft of a gear train driven by the synchronous motor.

(2) Increase the angular freedom of the table by adding an additional degree of freedom about the vertical axis and doubling the angular freedom about the horizontal axis.

The table electronics have been modified to:

(1) Provide a servo system for the operation of the precision rate drive described above.

(2) Provide electronics to operate the two-phase synchronous motor which operates the precision rate servo. This two-phase amplifier contains a unique 90-degree phase shift network which maintains a 90 ±1 degree phase relation between the voltages supplied to the synchronous motor through a frequency range of 60 to 600 cps.

(3) Provide a more flexible table servo system. Fundamental considerations prompted a complete redesign of the table servo system. This redesign greatly reduced the number of adjustments and some cross coupling of the adjustments in the original servo electronics.

(4) Provide a more sophisticated readout system. This readout system is being purchased from Northeastern Engineering. The system possesses the following improvements:

(a) Data are read directly onto punch paper tape, greatly facilitating computer data reduction.

(b) System flexibility provides for recording of gyro wheel rundown characteristics.

(c) Basic increase of test facility accuracy.

The basic ideas employed in this system were apparently conceived independently by STL and Northeastern Engineering working with MIT

The gyro electronics are being developed to provide:

(1) An electronic spin motor amplifier which will operate any gyro spin motor requiring less than 30 watts of power. The amplifier possesses the following characteristics:

(a) Two- to three-phase switching capability.

(b) Five- to 115-volt regulated output.

(c) Automatic start sequencer and interrupter for demagnetizing the hysteresis ring.

(2) Signal generator excitation and pickoff amplifiers with a switching capability from 400- to 1000-cycle operation, and, with minor modifications capable of operating at any frequency up to 6 kilocycles.

(3) Interchangeable dc and ac current balance amplifiers.

(4) A temperature control providing on-off or proportional control of gyro heat. The temperature control may be actuated by either resistance or contact-type temperature sensors.

(5) The microsyn excitation amplifiers will be regulated and have a current to voltage feedback switching capability to permit operation of gyros employing magnetic suspension

The servo table has been installed and rough-aligned. Except for the digital data recording system, all electronics are being designed and fabricated at STL employing existing circuit designs in use at MIT wherever possible. The electronics is about half complete; the expected completion date for the entire facility is May 1959. The test facility will be described in detail in a separate document.

3.3 A Study of Acceleration Measurement Techniques and Testing Methodologies

An inertial guidance system capable of missile application must include dependable accelerometers. The problems involved in accelerometer testing are similar to those encountered in gyro testing in that wide variations exist among various manufacturer test methods and definitions. There is also an intrinsic test problem due to the wide dynamic range required in accelerometers, in addition to the fact that laboratory simulations greater than 1 g are difficult. These factors have resulted in diverse test procedures more often predicated on the manufacturer's interest in demonstrating the virtues of his product than in conducting an over-all evaluation of his and other types of instruments. In view of this state of affairs, a need for an independent evaluation of accelerometer testing methods is apparent.

3.3.1 Study and Survey

An exhaustive survey of available acceleration measuring devices was undertaken for the acquisition of data on (1) accelerometers whose specifications fall within the limits of missile system applicability, and (2) test instrumentation devices to be employed in test methodology studies. The survey therefore included products with relatively immediate inertial guidance capability as well as those more distinctly associated with test purposes.

The products of 60 out of the 150 companies surveyed were incorporated into a master file. The breakdown and cataloguing of the manufacturer's information involved considerable interpolation and computation for at least two reasons: (1) diversified company specifications were not easily amenable to a uniform resolution, and (2) an attempt was made to keep the file as comprehensive as possible to cover many future inquiries and needs, including, for example, requests for information relating to a specific guidance system or instrumentation problem or to a test methodology study.

The file covers the following areas: (1) products of major producers of inertial components, (2) products of smaller companies with potential inertial guidance applicability, and (3) test and instrumentation devices for measurement of shock and acceleration. Such data as company model number, date of release, weight, range, etc., are included in the file. Since the file is in effect a critical breakdown of device parameters, it is capable of immediately assisting laboratory personnel as well as being available for system and technical direction inquiries.

Although the breakdown of inertial parameters and cataloguing of products have been substantially accomplished, completion and publication of the file has been temporarily delayed in consequence of Able-3 priority considerations.

The projected survey of current testing methods has been suspended because of a diversion of manpower to Project Minuteman.

3.3.2 Planning and Experimentation

A transistorized relay type servo system, control circuitry, and a test turntable were completed for the purpose of conducting pulse torque tests using a HIG-4 gyroscope. The circuitry was satisfactorily checked out open loop. A block diagram of the complete closed-loop configuration is shown in Figure 9.

Briefly the operation is as follows: An input angular rate fed into the HIG-4 gyroscope mounted on the turntable will cause output axis precession with a resultant signal generator voltage. This signal is amplified and phase detected in order to determine the sense of the precession. The logical circuitry develops a switch action to control the current pulses into the gyro torque motor via the power switch. The gimbal precession is thus restrained and the net pulse width, as measured by a precision clock, will represent the integral of the angular input rate. Two other approaches o pulse torquing are to be investigated. Recently some work was done at the MIT Instrumentation Laboratory* on a pulse torquing method which is very similar to one proposed in the last semiannual report. Continued work along the lines suggested by these reports is planned in view of the promising results they reveal concerning volume and weight reduction.

*A Pulse Restrained Accelerometer System, Report T-174, Instrumentation Laboratory, MIT.

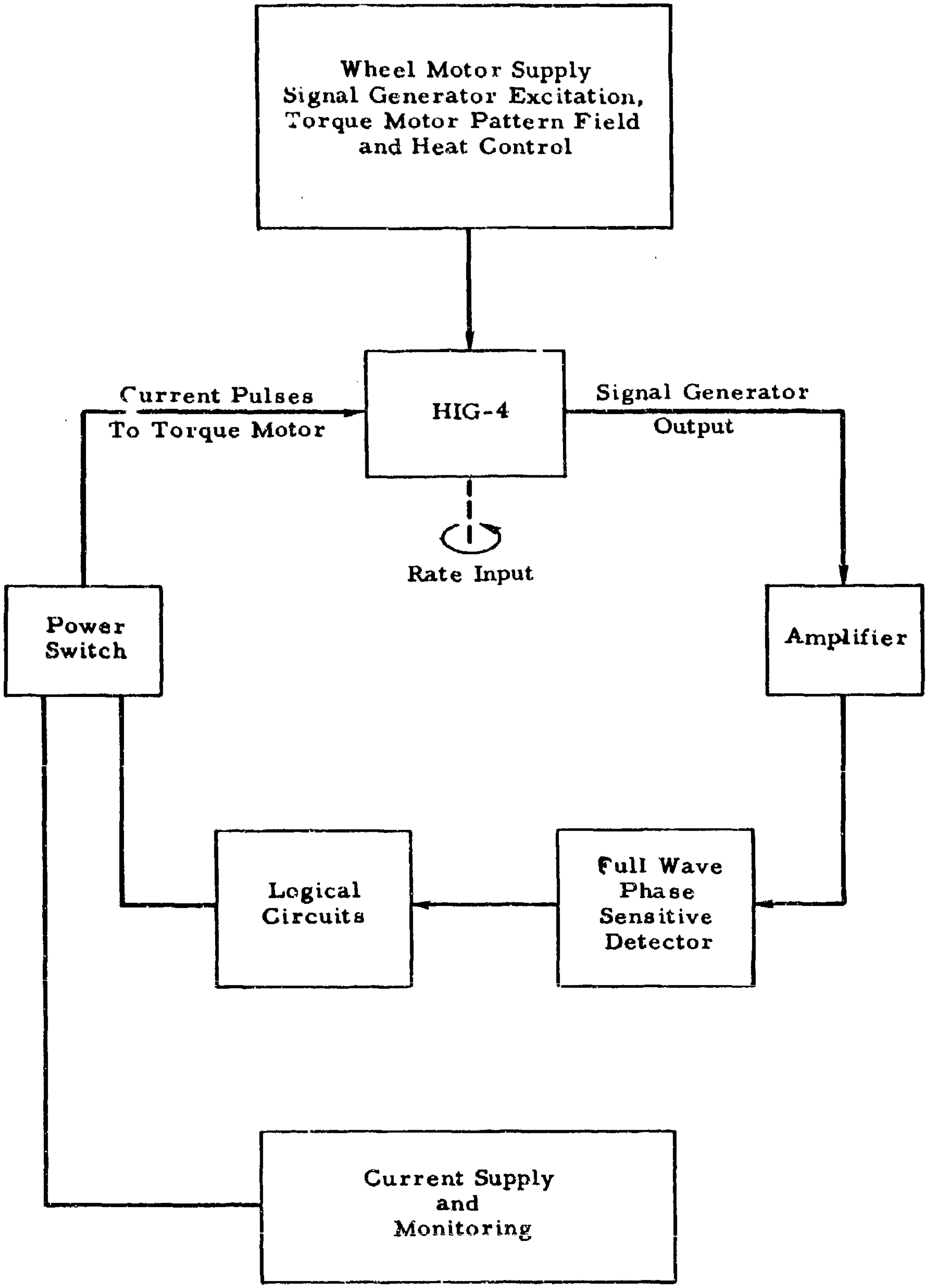


Figure 9. Relay Servo System for Pulse Torque Tests of HIG-4 Gyroscope.

a. Motor Tachometer Integration

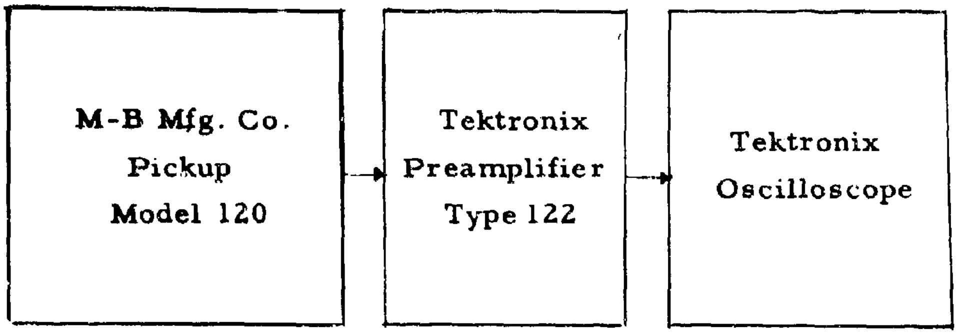
Studies of motor tachometer integration have been discontinued on the inertial components program since the work constitutes part of the development effort required on the integrating accelerometer for the Able-3 program. Results of this work, however, will be incorporated as they are relevant to the inertial components program.

b. Stable Pier Studies

A study of stable piers and vibration isolation problems continued as an aid to the evaluation of accelerometers. Investigation revealed that the most quantitative information on this subject is contained in the tests and evaluations of stable piers conducted by Minneapolis-Honeywell Regulator Company for their St. Petersburg, Florida, site. Minneapolis-Honeywell recorded vibration frequencies in the range from 10 to 100 cps. The vertical accelerations varied from 2×10^{-4}g at 30 cps to 3×10^{-3}g at 40 cps. No horizontal vibration measurements were made because of the 60 cps electrical pickup. The accuracy of these measurements is unknown.

Common types of vibration pickups measure velocity or acceleration. The velocity-type pickups are used above their natural frequencies (2 to 40 cps) and generate voltages proportional to velocity. Acceleration pickups are used below their natural frequencies (20 to 100,000 cps) and generate voltages proportional to acceleration. The voltage output of either type of pickup can be converted to indicate displacement, velocity, or acceleration with the conversion requiring a knowledge of the vibration frequency. In the work described below a velocity type pickup (M-B Model 120) was employed. The electrical output from this pickup is produced by the relative motion of a seismically mounted output coil in a permanent magnetic field. The voltage induced in the output coil is proportional to its velocity. Due to electrical noise, the minimum acceleration which can be measured by commercially available crystal-type accelerometers is approximately 1.0×10^{-3}g at 30 cps. The electrical noise level observed by Minneapolis-Honeywell using the M-B pickup was equivalent to 3×10^{-5}g at 30 cps. In our work, a battery powered preamplifier was used, reducing the noise to about 1×10^{-5}g at 30 cps.

A series of vibration measurements were made at STL. The test equipment consisted of an M-B Model 120 pickup connected to a battery operated preamplifier and oscilloscope as sketched below.



The pickup was placed at various locations on the laboratory floor and the vibration amplitude was observed visually on the scope. Readings were taken with the sensitive axis in the pickup both vertically and horizontally. The amplitude was measured by using the calibrated vertical amplifier in the scope and assuming that the pickup calibration stated by the manufacturer was correct. The over-all measurement accuracy is probably no better than 20 per cent. A method for calibrating the pickup unit independently is under investigation.

It was found that essentially all of the vibrational energy was between 10 and 200 cps and that the predominant vibration centered about 20 cps. In general, the vibration levels were lower at the walls of the rooms by about a factor of 2 compared to the vibration level in the center of the floor. The vertical vibration levels were in the range of 1×10^{-4}g to 8×10^{-4}g rms and the horizontal vibration varied from 3×10^{-5}g rms at 10 cps to a maximum 1×10^{-3}g rms at 60 cps.

Vertical vibration measurements were also taken on the floor and on a 2- by 3-foot granite surface plate mounted on a standard angle iron frame. These results indicated a resonant condition on the surface plate at 20 cps with an amplification factor of 10. Since accelerometer testing requires a stable mounting, various improved designs are under investigation to reduce the vibration amplification of the mounting.

One approach has been to cast a solid block of concrete directly on the floor to replace the angle iron frame mentioned above. Preliminary tests on this mounting indicated amplification factors of the same order of magnitude as the angle iron framework for vertical vibration. The concrete block is 2.5 feet high and 4.5 by 1.5 feet in horizontal cross section. Further measurements will be made to determine the transmissibility more precisely. A second approach is to use a heavy wood frame mount for the surface plate. Design of this mount is under way.

3.4 An Evaluation of Free-Floated Gyro Performance

Two obvious considerations in the choice of components for ballistic missile applications are accuracy and weight. Inertial components which indicate favorable potentialities in this direction require study and evaluation under laboratory conditions. A program was accordingly undertaken to investigate the suitability of two-degree-of-freedom floated (TDFF) gyros to such ballistic missile application as flight safety and missile control systems.

3.4.1 Study and Survey

TDFF gyros are manufactured in two basic configurations differentiated by small and large gimbal travel. A survey of gyro producers indicates that only four American Manufacturers produce TDFF gyros of the liquid floated instrument type. These are the Arma, Litton, Kearfott, and Daystrom Pacific Corporations. The Arma and Litton gyros have small gimbal freedom; the Daystrom and Kearfott units have large gimbal travel. Since gyros with large gimbal freedom were the only ones of interest for the applications considered, only the Daystrom and Kearfott gyros were required in the evaluation program. Two units were received from Daystrom, but receipt of three gyros to be procured under the auspicies of AFBMD is still forthcoming. AFBMD had also previously directed General Electric to send free gyros to STL for program evaluation. The three gyros requested have not been received and no information regarding their disposition has been obtained.

3.4.2 Planning and Experimentation

As stated above, this program sought to determine the applicability of TDFF gyros to ballistic missile safety and control systems. The gyro consisted

of a rotor mounted in a two-gimbal suspension system which is free to rotate through large angles. The entire gimbal system is floated in a high density fluorocarbon polymer oil. Synchro pickoffs and ac torquers are attached to the inner and outer gimbals. Figure 10 shows a simplified schematic diagram of the TDFF tested.

A test plan was written and work commenced in the last quarter of 1958. Performance parameter and reliability under controlled environmental conditions simulating IRBM and ICBM operations were studied.

a. Test Equipment

The Inertial Components Laboratory of STL designed and constructed the following test equipment for evaluation of TDFF gyros:

(1) Gyro and power patch panel.

(2) Amplifier patch panel.

(3) Two-axis gyro test panel.

Tests conducted to date have used (1) and (2). Fabrication of the two-axis test panel has been completed, but checkout of the amplifier is still in progress.

b. Test Program

The test program was divided into four major parts:

(1) Design and construction of erection circuit.

(2) Bench testing.

(3) Environmental testing.

(4) Analysis and study of test results accruing to (1) and (2).

c. Erection Circuit Design

An erection circuit to provide a means of orienting the inner and outer gimbals with respect to the gyro case was designed and breadboarded utilizing components in the laboratory. Means of gyro torquing have been investigated which utilize torquing power independent of the gyro pickoff

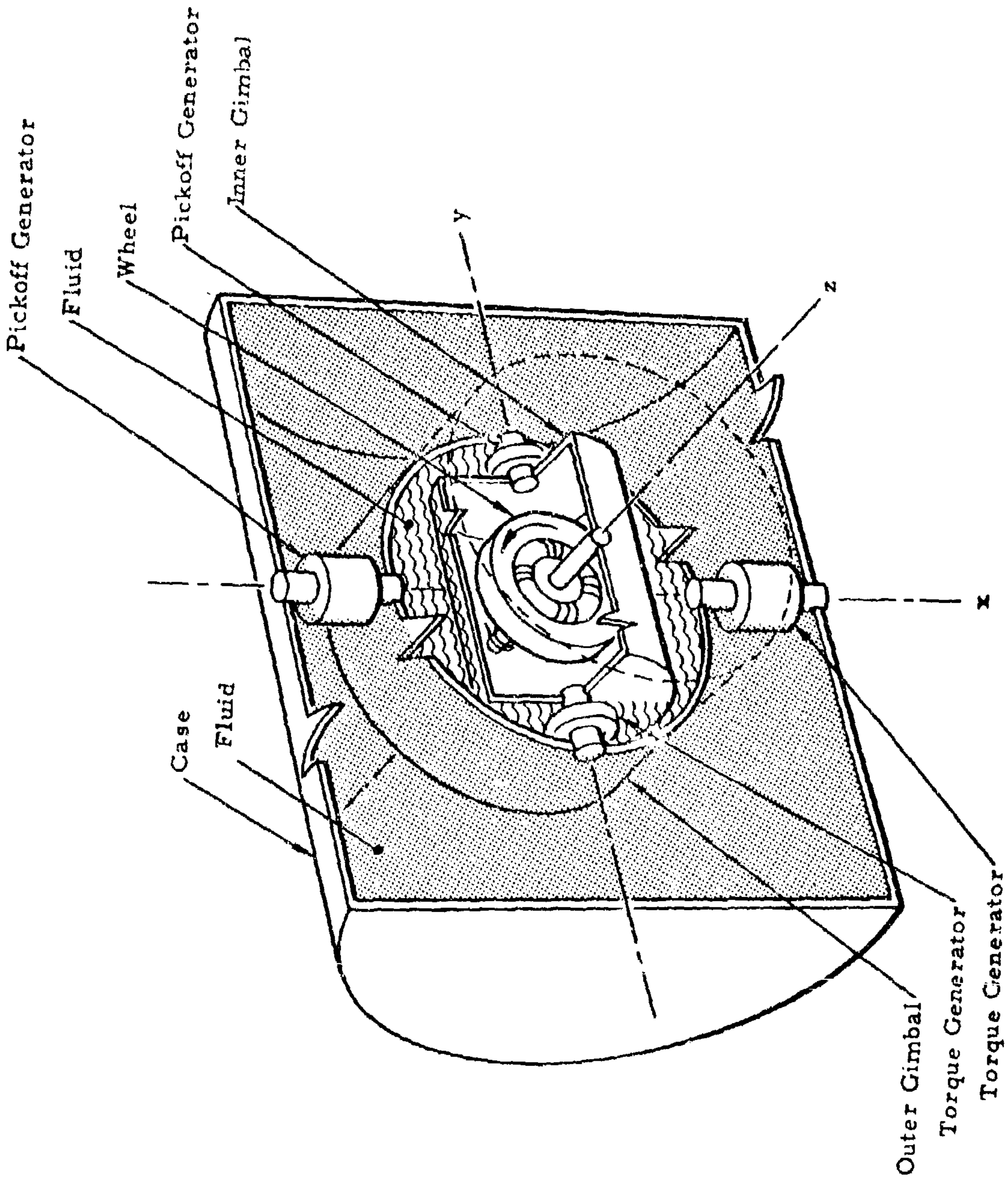


Figure 10. Simplified Schematic of TDFF Gyro.

(as shown in Figure 11) as well as by a closed-loop method between the gyro pickoff and torquer, shown in Figure 12.

d. Bench Testing

Numerous bench tests were undertaken concurrently with fabrication of the gyro erection circuit. These tests determined the degree of gyro performance and the consequent worth of sustaining the tests.

One of the gyros failed to perform correctly after a short operating time and all testing of this unit was discontinued. The failure occurred after an approximate running time of 15 minutes when motor slowdow began. This may be attributable to a spin bearing failure or heat expansion of materials.

The second gyro underwent tests in the following areas: weight and dimension, resistance and continuity, motor characteristics, signal and torque generator characteristics, gyro polarity, gimbal freedom, erection of alignment, cross coupling, null shifts, and open-loop drift tests. Preliminary results indicated possible stiction of the gyro and the open-loop drift tests indicated drift rates much less than the corresponding component of the earth's rate. Scorsby tests (wobbulation) showed no increase in drift rates over static bench operation; however, at the end of the test period it was noted that the signal generator exhibited discontinuous shifts, indicating internal movements within the gyro unit. It was concluded therefore, that the second unit was also performing incorrectly. Further testing will be undertaken on receipt of the anticipated additional test unit cited in paragraph 3.4.1 above.

Mode 2

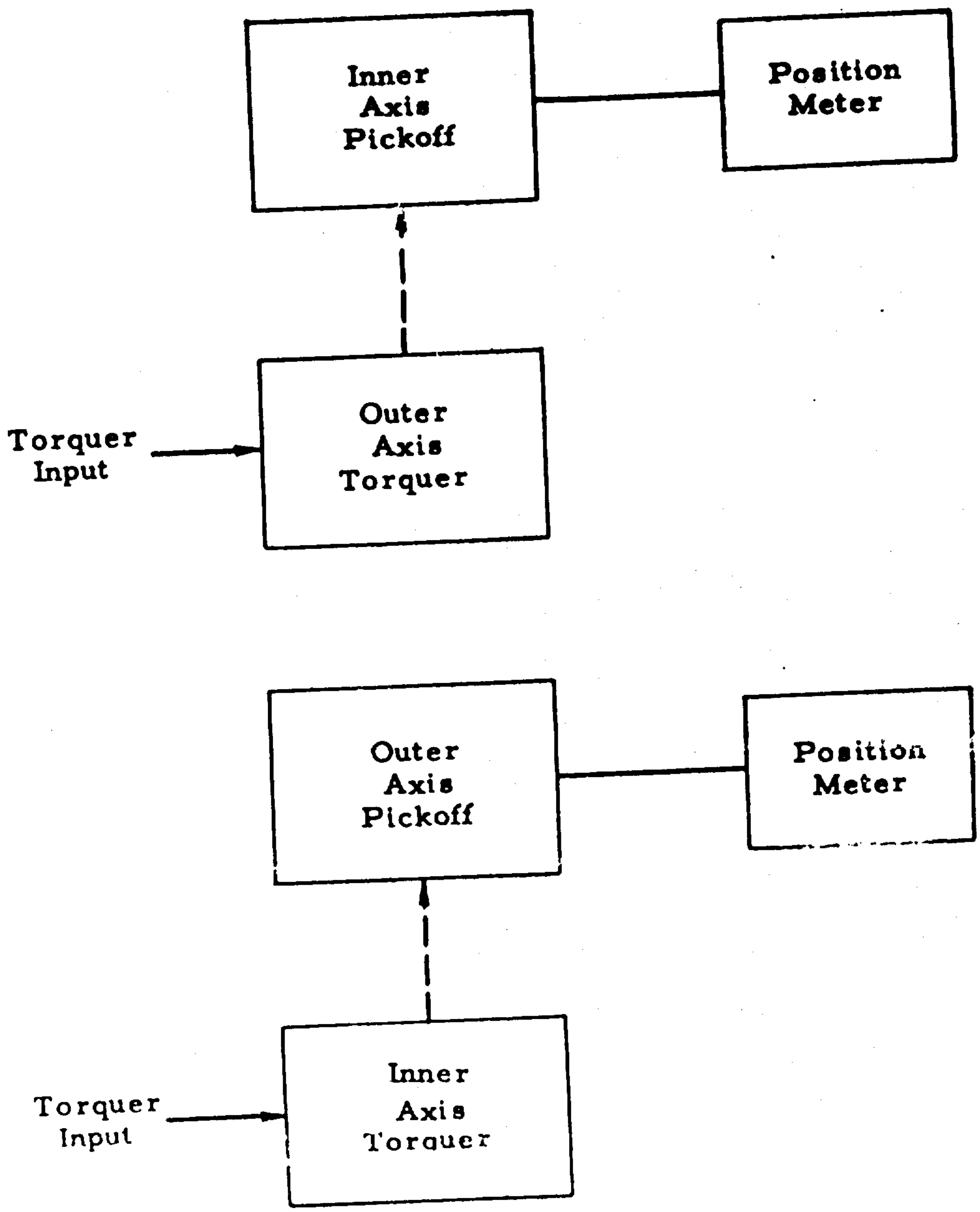


Figure 11. Independent Gyro Torquing Method.

Mode 1

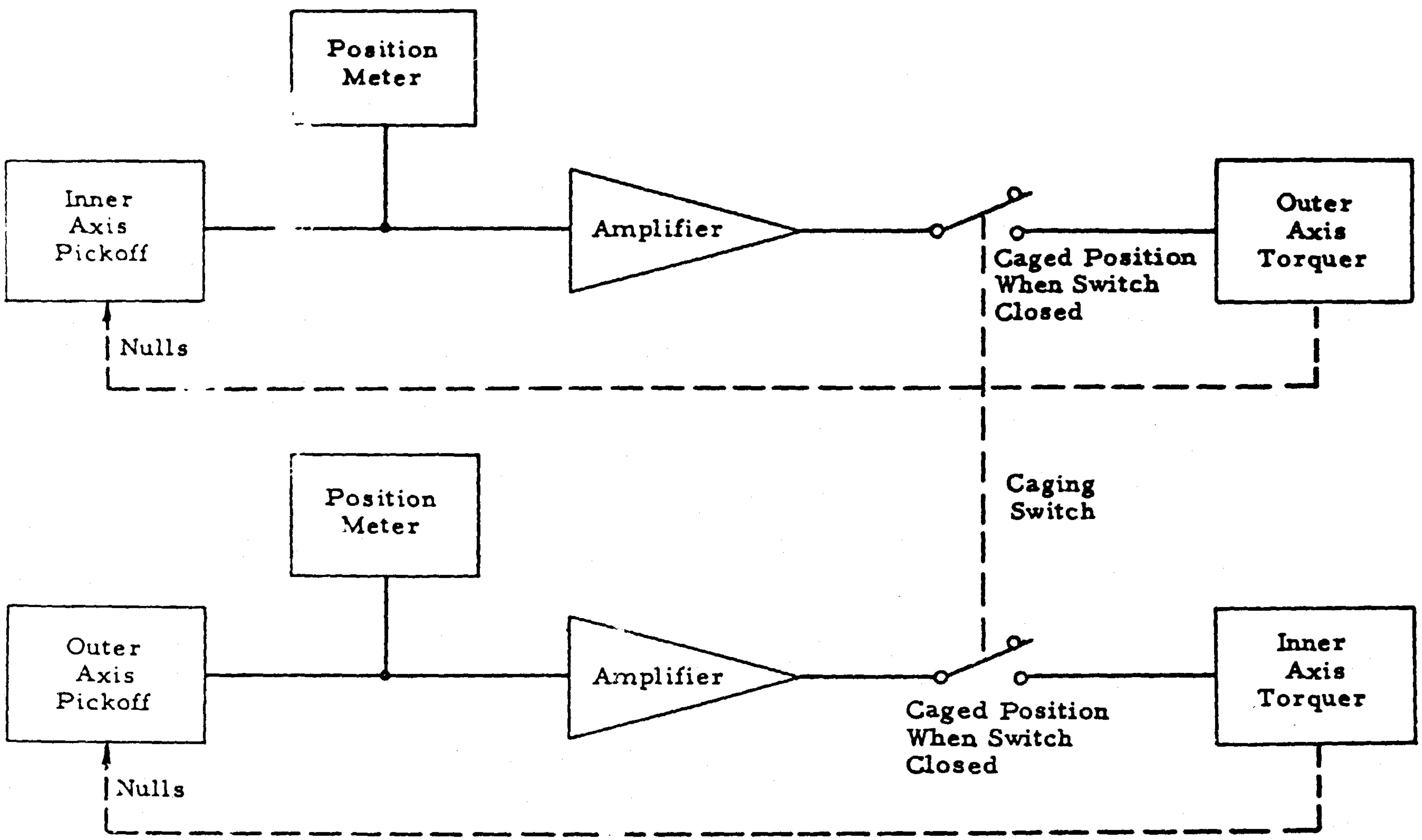


Figure 12. Closed-Loop Gyro Torquing Method.

4. TECHNICAL PLANS

For the period from 1 January 1959 to 31 December 1959, STL will continue studies of inertial components and inertial measurement systems in support of systems engineering and technical direction of the ballistic missile weapon system programs. A capability will be maintained for investigation of critical problem areas arising in the current development programs and for generation of rapid fixes when required.

Among the areas to be investigated are:

a. Evaluation of inertial components used (or proposed for use) in the ballistic missile weapon system.

b. A study of testing methodology and measurement techniques used in the evaluation of precision gyros and accelerometers.

c. Investigation of ferro-magnetic materials stability.

d. A study of operational flight safety system.

Evaluation of the Arma gyro and accelerometer and the Daystrom free gyro will be conducted under (1). Preparation for evaluation of the Autonetics gyro and accelerometer will also be initiated.

The availability of these components in early 1960 is anticipated.

5. BIBLIOGRAPHY

a. Inertial Components Test Plan No. 5, Two-Degree-of-Freedom Floated Gyro, GM 43.8-196, 20 May 1958.

b. Semiannual Report on Inertial Components Program, GM-TR-0165-00443 1 January - 30 June 1958.

c. A Detailed Plan for Study of Resonance Conditions in Arma Accelerometer, GM 43-461, 17 November 1958.

d. Specification for Digital Data Gyro Test Recording System, GM 43.8-284, 25 November 1958.

e. A Drift Stability Test Plan for the Arma Gyro, GM 43.8-301, 9 February 1959.

DISTRIBUTION

J.R. Burnett

L.G. Dunn

R.L. Gates

G. Gleghorn

A.B. Graybill

G. Harter

F.W. Hesse

L.K. Jensen (15)

H. Lassen

T. Layton

L.K. Lee

H. Low (2)

R. Merbach

G.E. Mueller

E. Robb

W.T. Russell

J.D. Sorrells

E.R. Spangler

D.T. Wallace

H.Y. Wong

H. Yost

R. Zacharias

STL Library (2)

WDSOT (17 + 1 reproducible)